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Dentate transport discs can be used to reconstruct large segmental mandibular defects

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Abstract

Purpose—This study tests the use of a dentate transport segment for the reconstruction of a large U-shaped defect in the anterior segment of the canine mandible, using a novel curved reconstruction plate. The quality and quantity of bone regenerate formed by dentate versus edentulous transport segments was compared.

Methods—In five adult foxhound dogs, a defect of 70–75 mm was created in the canine mandible by excising the mandible anterior to the right and left 4th premolars. Reconstruction was done by trifocal distraction osteogenesis using a bone transport reconstruction plate (BTRP-02TM), with two transport units being activated simultaneously, one on either side of the defect, one dentate and one edentulous. Bilateral distraction proceeded at a rate of 1mm/day until the segments docked against each other in midline. After 39–44 days consolidation, the animals were

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euthanized. The quantity and quality of bone regeneration on both sides were compared using micro-computed tomography.

Results—The defect reconstruction was successful. The amount and quality of bone formed by the transport segments was similar on both sides. There were no significant differences in the bone volume fraction and density of the regenerate bone formed by the two transport segments. The bone volume fraction and density of the regenerate was significantly lower than that of the host bone in the distal segments, likely due to the short consolidation period.

Conclusions—Bone transport remains a viable option in reconstructing anterior segmental defects in the mandible. The use of either dentate or edentulous transport segments for reconstruction provides options for the surgeon in often highly compromised patients requiring these surgeries.

Keywords

Bone transport; distraction osteogenesis; micro-computed tomography; bone volume; density; dentate

INTRODUCTION

Reconstruction of massive anterior defects in the mandible is challenging. Restoring the three-dimensional projection of the chin with adequate bone height and thickness to allow for functional rehabilitation of the dental arch is difficult to achieve with traditional grafting techniques. Distraction osteogenesis can overcome many of the limitations of conventional reconstruction methods.

Distraction osteogenesis was popularized in the field of orthopedic surgery by the work of Ilizarov, which illustrated that mechanical forces applied across osteotomy lines can stimulate and guide the synthesis of bone as well as the surrounding soft tissues.^{1–5} By the end of the twentieth century, the bone lengthening technique proved to be useful in correcting facial deformities.² It is important to consider the three main advantages of distraction over conventional bone grafting. First, the new bone formed by distraction osteogenesis is a vital tissue from the start, with cells, blood vessels, and nerve supply, unlike a bone graft. Secondly, its physical dimensions and mechanical properties are comparable to native bone, making the rehabilitation potentially easier.^{6,7} Thirdly, the bone is covered by soft tissues from the beginning, making it an ideal option for reconstructing large bone defects in the jaw.^{3,5}

A modification of distraction osteogenesis, bone transport distraction osteogenesis, has shown great promise in reconstructing bone defects in the extremities.^{8–10} Bone transport distraction involves the gradual movement of an osteotomized bone segment along a transport track spanning an existing bone defect. Clinical case reports have illustrated the advantages of this technique, especially in difficult cases where traditional grafting procedures are unfeasible or have failed.¹¹

There have been concerns regarding the distraction of teeth and tooth-carrying bone segments.¹² Typically, the rate of orthodontic tooth movement has been slightly less than

1mm per month, while the rate of distraction osteogenesis is typically 1mm per day.^{13,14} Multiple studies have demonstrated the successful distraction of teeth, along with surrounding bone without any damage to the vitality of the tooth.^{15,16} Dento-alveolar distraction techniques demonstrated that teeth can be distracted successfully without loss of anchorage, fracture or root resorption.¹⁷ On the other hand, a previous study demonstrated radiographic and histological evidence of extensive lateral and apical resorption and loss of lamina dura in teeth moved into the regenerate after one week of consolidation.¹⁸ In none of these procedures was the intent to create new bone, but rather to move teeth into new positions.

The purpose of the present study was to prove the feasibility of reconstructing the entire U-shaped anterior segment of the canine mandible using a one-stage internal device that follows the outline of the original mandible, and compare the bone regenerate produced by dentate and edentulous transport discs within the same animal. Our hypothesis was that the reconstruction of such a challenging defect would be feasible and the bone regenerate comparable between the dentate and edentulous sides. Our specific aims were to 1) test the use of a curvilinear version of a novel device, the mandibular bone transport reconstruction plate (BTRP-02™),¹⁹ to distract two transport segments distal to proximal simultaneously, one on either side of the large defect, and 2) compare the amount and quality of bone produced by dentate and edentulous transport bone segments within each animal using micro-computed tomography (μ-CT).

MATERIALS AND METHODS

Study design

Five adult male fox hounds were used in this study, with an average weight of 70 pounds. A bone transport osteogenesis reconstruction of a canine mandibular defect model was used. The housing, care and experimental protocol were in accordance with the guidelines established by the Institutional Animal Care and Use Committee at Texas A&M University Baylor College of Dentistry (TAMBCD), Dallas, TX. In each animal, a full-thickness curvilinear defect (~70 mm-long) was created in the mandible by surgical excision of the bone anterior to the right and left fourth premolars. A bone transport reconstruction plate (BTRP-02™, Craniotech ACR Devices, LLC, Dallas, TX) was used to stabilize the mandibular bony stumps and create regenerate across the gap (Figure 1). The bone transport device is composed of a U-shaped titanium reconstruction plate that is curved to fit the anterior shape of the mandible, and spans the midline. Each end of the plate has 4–5 holes for 2.7 titanium screws while the mid-section is threaded to serve as a track for bone transport. Two transport units were mounted on the transport track, one on each side of the defect. Each unit has two wing-shaped plates that accommodate 4 × 1.7 titanium screws to secure the unit to a transport bone segment (transport disc). A 360° revolution of the activation screw located within each transport unit causes the unit to travel 1mm along the transport track.

Variables

Independent variable—The transport disc was dentate on one side and edentulous on the other. Dependent variables: The quality and quantity of bone regenerate was compared between the right and left sides using cone-beam CT and microCT as detailed below. Other variables such as animal age, gender, and weight, surgical procedure, and duration of distraction and consolidation were the same in all animals as described below.

Sample collection—At euthanasia, the right common carotid artery and internal jugular vein were explored and incised after anesthetizing the animals. The head and neck region was then perfused with 10% formaldehyde. The mandibles were then harvested in one piece after removing the BTRP device, and the rami sectioned behind the last molar. Samples were placed in individual containers filled with 10% formaldehyde.

Surgical procedure—Before surgery, prophylactic root canal treatment of the maxillary canines on both sides was done to avoid the risk of damage during surgery as well as to prevent them from obstructing the transport segments. The fourth premolar on the left side was extracted one week prior to surgery. On the right side of the mandible, the fourth premolar (to be included on the transport segment) was endodontically treated, one week prior to surgery. Food, not water was withheld from each dog for 24 hours prior to surgery in order to avoid regurgitation and bloating. Before surgery, each dog was injected with atropine 2mg/100 lbs SQ. This was given fifteen minutes prior to pre-anesthetic of diazepam 0.5mg/kg IM. Once the animal was sedated, isoflurane was administered via a mask. The isoflurane was administered at 4% in 100% oxygen with a flow rate of 3 to 4 liters per minute. Next, endotracheal intubation was carried out with a size 10 tube, and the animal was maintained on isoflurane at 1–2% in 100% oxygen at a flow rate of 0.5–2 liters per minute, depending on the tidal volume. At that time, dogs were given penicillin G procaine with penicillin G benzathine at a dose of 300,000 IU./25 lbs SQ. This dose was repeated every 3 days post-operatively for 2 weeks.

Under general anesthesia, the animal was secured to the operating table in the supine position. Using aseptic conditions, a U-shaped incision was made in the skin overlying the lower border of the mandible. The buccal surface of the mandible was then exposed through an extra-oral approach. Bone was exposed by sub-periosteal dissection, except over the bone segment to be removed where dissection proceeded supra-periosteal. Then, the plate component of the device was adapted to the buccal surface of the mandible and the first two screws on each side were drilled in to mark their position before removing the bone. Taking care not to fracture the bone, an osteotomy along the buccal cortex was made between the third and fourth premolars on each side, marking the beginning of the bone segment to be excised, and a corticotomy posterior to the fourth premolar was done to outline the transport segment. Osteotomies were done using a reciprocating mini-saw (Stryker Craniomaxillofacial, Portage, MI). Then, the screws and the plate were removed. The mandibular bone anterior to the fourth premolars on both sides was completely dissected from the lingual side and the osteotomy on the right and left were completed through the entire thickness of the cortical plate. Care was taken to isolate and ligate the inferior alveolar neurovascular bundles to prevent massive bleeding before excising the bone. The bone

segments were spread apart for a few millimeters to allow for ligating a loop of 3-0 black silk suture around the neurovascular bundle before incising it distally to the ligation. After excising the entire anterior portion of the mandible, the plate was re-positioned using the pre-drilled screw holes as guides. The length of the U-shaped defect was 70–75mm. The bony stump on each side received at least three bicortical screws to secure the plate. Then, the corticotomies posterior to the position of the fourth premolars were completed to separate the right and left transport bone segments (15mm mesial-distal), only one of which carried a viable tooth. On the opposite side, extraction of the fourth premolar under similar anesthetic conditions was completed one week earlier to create an edentulous transport disc. Each of the two transport discs was secured to one of the two transport units of the device using at least three 1.7 titanium mini-screws per wing. The burrs and saw blades were cooled while in contact with the bone using continuous irrigation with sterile saline. In addition to preserving the inferior alveolar vessels proximal to the transport disc, dissection of the lingual mucosa was kept to a minimum to maintain the vitality of the bone disc. The soft tissue was then closed in layers using 3-0 Vicryl sutures. The floor of the mouth was securely sutured to the anterior (middle) portion of the plate for a few days to prevent soft-tissue contracture.

Post-operative care

An occlusal radiograph was taken immediately after surgery to confirm the correct position and stabilization of the plate and transport discs. The animals were kept under close observation until fully awake before moving them back to their cages. Buprenorphine was administered at 0.0005 mg/kg SQ every 12 hours for pain. The animals were allowed to eat soft food the next morning ensuring that they were able to chew comfortably. For the remainder of the study the animals were fed a soft food diet comprising regular pellets ground to a powder and mixed with wet canned food and water. They were closely monitored for the remainder of the experiment for signs of bleeding, infection, or feeding problems.

Bone transport distraction

Starting on the 3rd day post-operative, activation of the right and left transport units commenced at a rate of 1mm per day. Each transport unit of the device had a screw head protruding through the mucosa. It was activated with a hex key once daily. As the transport segments reached the curved portion of the reconstruction plate, the device was activated 1.5 mm per day to prevent premature consolidation of the inside surface of the bone. The progress of the distraction and consolidation was assessed through biweekly occlusal radiographs (Table 1). Short-term sedation during screw activation was sometimes needed initially to prevent discomfort. Bone transport was continued for an average of 5.5 weeks until the transport segments met at the midline. After 6 weeks of consolidation, the animals were euthanized using Beuthanasia-D (1mL IC while under anesthesia) in accordance with the recommendations of the panel on Euthanasia of the American Veterinary Medical Association.

Cone beam computed tomography (CBCT) measurements

To analyze the physical dimensions of the regenerate, the specimens were scanned using an i-CAT machine (Imaging Sciences International, Hartfield, PA) under 120Kvp and 0.4 mm voxel size. The exposure time for each specimen was 20 seconds for 0.4 mm scans. Each mandible was oriented with the occlusal plane aligned horizontally on top of a custom designed platform of the i-CAT machine. The CBCT scans were saved as single-DICOM files and imported into ANALYZE 3D Imaging Software. (ANALYZE Imaging, Overland Park, KS). A certified technician in the Oral Radiology Center at TAMBCD acquired all the scans.

Three-dimensional μ -CT scans

After CBCT, mandibles were then sectioned for further analysis. Each mandible was initially sectioned into three segments, the two bodies and the anterior midline region containing the two transport segments. Each body was then subdivided into three blocks: the native bone adjacent to regenerate (distal), the center of the regenerate (middle) and the anterior portion of the regenerate just behind the transport segments (proximal). Distal, middle and proximal bone blocks from both sides of the mandible were initially scanned with an average of 800 to 1000 slices using a SCANCO μ -CT-35 (Bruttisellen, Switzerland) at 37 micron voxel resolution, in tubes 75mm length and 35 mm diameter. Each specimen was stabilized within the tube using a piece of foam at the bottom and covered by paraffin film. All measurements and three-dimensional reconstruction was done using the SCANCO software. Thereafter, 100 slices in the center of each block were chosen to run a higher-resolution scan at 20 micron voxel resolution. A consistent volume-of-interest was identified. The region was contoured for subsequent quantitative measurements by the selection of appropriate upper and lower threshold values in order to ensure the separation of mineralized and non-mineralized structures. For each regenerate sample, the threshold values were assessed for each measurement. The average of those values was taken to arrive at the final upper and lower limit of 1000 and 180 for both the regenerate samples in each dog. The Gauss sigma and support values were kept at 1.5 and 1.

Statistical analysis

Statistical evaluation of the results of the bone volume analysis, bone trabecular morphometry and mid-shaft evaluation of the regenerate bone was done with two-way analysis of variance (ANOVA) parametric tests. The measurements compared were bone volume fraction (BV/TV), structural model index (SMI), connectivity density (Conn.D), trabecular number (Tb.N), trabecular thickness (Tb.Th), trabecular spacing (Tb.Sp), material density and apparent density. All calculations were carried out using the SPSS software version 17.0, (IBM, Armonk, New York).

RESULTS

Gross morphological appearance antemortem

The surgical procedure went well for all the animals with no excessive bleeding or injury to the inferior alveolar nerve bundle supplying the transport discs. The animals recovered well during the post-operative period.

On routine clinical examination during the distraction period, extensive granulation tissue formation was noted within the gap as the distraction period progressed, especially anterior to the transport segments. Dog 1 showed a slight area of exposed bone on the dentate transport disc but did not show as much granulation tissue. Dog 2 showed some callus formation anterior to the transport disc. Highly vascular soft tissue masses formed anterior to all the transport segments. As the transport discs approached the midline, the soft tissue became progressively compressed. At the termination of bone transport, a layer of soft tissue from each side separated the two transport discs. In 4 out of 5 animals, the device was activated uneventfully until docking. Dog 3 required a longer activation period because of a malfunction in the wing of the transport unit of the device. However, distraction was completed successfully in this animal. The device and bone segments remained stable throughout the consolidation period. The animal's daily food and water consumption remained satisfactory, and animals were able to feed unaided.

Complications during active distraction

- In three animals, the upper part of the buccal plate of one of the transport segments became exposed during the distraction period. The exposed bone became necrotic and the screws of the upper wing of the transport unit in dog 2 on the right side loosened during activation, and were removed. All the lower screws remained intact. There was no sign of infection in any animals.
 - a. Tissue irritation: There was some irritation caused by the transport unit in dog 2, on the inner portion of his upper lip on the left and under the right side of the tongue. To treat that irritation, the wing portion of the unit (from which the loosened screws had been removed) was reduced down to the gingival level using a bur, to avoid further irritation of the mucosa. Either wax or bond adhesives (like composite or bonding cement) were used to prevent irritation by exposed metal. Local irritation of the gingiva in some animals was apparently caused by the stainless steel components of the device, especially in the transport unit.
- Device malfunction: In dog 3, the right-side transport disc stopped moving due to deformation of the wings. The wings of the device were replaced with new ones and secured tightly and the unit was re-activated and functioned correctly. Dog 3 was therefore distracted for a longer period of time compared to the others (Table 1).

Radiographic Examination

Weekly radiographs of the mandibles demonstrated a steady increase in regenerate volume and density as distraction progressed (Figure 2). By the end of distraction, the trabeculation was comparable on both sides of the mandible. By the end of the consolidation period, the regenerate bone appeared more radiopaque than during the distraction period. The midline docking site between the two transport discs continued to show non-union of bone, with an intervening mass of soft tissue apparent between the bone stumps.

Gross Appearance on Resection

The symphysis region of the regenerate in most dogs appeared to be held together by soft tissue and showed signs of free movement on manual handling except for Dog 4, in which the symphysis was relatively stable. There was some difficulty in removing the lower wing of the device from dog 4, which required a high-speed drill. There were yellow specks of mineralized bone seen throughout that region.

Cone-Beam CT

On a sagittal view of the body of the mandibles, the height of the regenerate bone in all the animals was comparable to that of the native bone distal to the regenerate (Figure 3A, B). Anterior and inferior views of the midline region showed an open gap in all animals except dog 4, indicating that the regenerate stumps were most likely held together at the symphysis by soft tissue (Figure 3C, D).

Micro-CT

μ -CT reconstructions were done on the distal, middle and proximal segments of the mandible bodies, and on the midline segments comprising the transport discs. The midline region of all mandibles showed well-mineralized transport discs with tooth roots (Figure 4A, B) or intact teeth (Figure 4C, D, E) in the right side transport discs. All teeth remained intact, but μ -CT did not capture complete views of all teeth. Three out of five animals showed signs of bony union at the midline (Figure 4A, C, D).

All distal segments comprised bone distal to the regenerate, and showed the presence of a thick cortical plate and a well-defined alveolar canal. The middle and proximal segments were fully within the regenerate. A dense trabecular network was visible in all segments, and some segments showed the beginnings of a cortical plate. A continuation of the alveolar canal space was also present in all segments. The bone trabeculae in the middle segments of the regenerate behind the dentate transport discs appeared less organized than those in similar regions behind the edentulous transport discs (Figure 5).

No statistically significant differences were detected between the right and left sides in BV/TV, SMI, Conn.D, Tb.N, Tb.Th, Tb.Sp, material density or apparent density (Figure 6). However, the bone parameters in the distal segments behind the regenerate showed consistently higher BV/TV, Tb.Th, Tb.Sp, material density and apparent density than bone within the regenerate segments, and lower Conn.D and Tb.N.

DISCUSSION

The purpose of the present study was to prove the feasibility of reconstructing the entire U-shaped anterior segment of the canine mandible using a one-stage internal device that follows the outline of the original mandible, and compare the bone regenerate produced by dentate and edentulous transport discs within the same animal. Our hypothesis was that the reconstruction of such a challenging defect would be feasible and the bone regenerate comparable between the dentate and edentulous sides. Our specific aims were to 1) test the use of a curvilinear version of a novel device, the mandibular bone transport reconstruction plate (BTRP-02™),¹⁹ to distract two transport segments distal to proximal simultaneously, one on either side of the defect, and 2) compare the amount and quality of bone produced by dentate and edentulous transport bone segments within each animal using micro-computed tomography (μ-CT).

Bone transport distraction was completed successfully in all animals, with adequate bone formation within the distraction gap. The U-shaped outline of the mandibular bone was restored and there was adequate support to the soft tissues of the mouth floor. The newly formed bone was comparable in dimensions and quality to the original mandible. There was no difference in bone regeneration produced by the dentate and edentulous transport discs. Some animals demonstrated bony and fibrous tissue union at the midline between the two transport discs, while others had non-union.

These results confirm a previously published clinical case report on the reconstruction of a comparable mandibular defect.¹¹ There have been reports in the literature of tooth transport through distraction osteogenesis. However, in these studies, the tooth was being moved into bone regenerate where a cortical plate was compromised, or not yet formed. In these cases the question of timing of tooth movement into regenerate bone was the issue. Some previous studies reported that premature movement of teeth into bone regenerate was harmful,^{12,20,21} whereas others recommended waiting for 8 to 12 weeks for consolidation to produce a good outcome.^{22–31} In the present study, the tooth was moved within an entire segment of bone that was maintained as a viable transport disc all along the distraction distance. A recent study has shown that a toothed bone segment can be transported orthodontically for short distances.³²

There are multiple novel aspects of the present study. First, it tested the reconstruction of a very large (75mm) and complex (U-shaped) defect in a large animal. Secondly, it tested a novel internal bone transport distraction device, where the transport track is the reconstruction plate itself, which provides more stability and easier access, and allows the transport to follow the outline of the original mandibular arch. Thirdly, the study shows for the first time that a tooth can be transported in a regular bone transport disc, over large distances, using a standard distraction protocol. Furthermore, the teeth remained intact and were visible in the transport discs at the end of the consolidation period. In this study the teeth in the transport disc were subjected to root canal therapy prior to transport. This was to preclude additional surgeries that would be required should the screws from the transport units penetrate the roots of the teeth. No evidence of root penetration by screws was seen, so the possibility exists that intact teeth may be able to be transported in this manner. This form

of transport could therefore be considered similar to standard distraction protocols for lengthening the mandible.

For patients afflicted with neoplasm of the mandible, surgery is often the only option. The treatment plan can involve en-bloc resection followed by mandibular reconstruction. This stage of mandibular reconstruction is arguably the most pivotal in deciding the quality of life of the patient. Distraction osteogenesis, specifically bone transport distraction osteogenesis (BTDO) has been looked into as a promising option for reconstruction of mandibular defects. However, despite the outstanding results of distraction osteogenesis in orthopedic surgery, this procedure has failed to gain momentum in the reconstruction of craniofacial bones. One reason is the high incidence of device failure during the extended periods of distraction for very large defects. This animal study demonstrated the potential of reconstructing an extremely challenging U-shaped defect using a bone transport device. This device can carry two transport discs on a single reconstruction plate, one on either side of the defect, halving the distraction time.

When reconstructing large segmental defects in the mandible, a titanium reconstruction plate is often used to stabilize the mandibular stumps, whether or not additional reconstructive methods are used.³³ Currently, the gold standard for reconstruction of these large segmental defects in the mandible is autogenous, especially vascularized, bone grafts.^{34,35} However, this technique is associated with numerous complications.^{34–36} It remains to be seen if recent advances in tissue engineering techniques including distraction osteogenesis can provide a reliable method for reconstructing the mandible without involving a bone graft.³⁷

BTDO induces new bone formation in a segmental defect; bone that is not only viable, but also similar in dimensions, outline, and mechanical properties to the original bone.^{19,38} Furthermore, distraction forces induce the growth of the soft tissue coverage along with the bone, an extremely challenging, yet essential, requirement of skeletal reconstruction. However, a limitation of bone transport techniques in the maxillofacial area has been the occurrence of dehiscence of the covering soft tissues, which could be problematic for maintaining regular diet and controlling infection. In the present study, however, all animals showed complete healing of the floor of the mouth without significant dehiscence of the soft tissues.

This study used a modified version of a novel bone transport device, (BTRP), where the bone transport disc is carried along the supporting plate itself, instead of on a mounted track.¹⁹ The modified version comprised a curved track spanning the gap produced by complete resection of the anterior mandible. This curved reconstruction plate allowed the placement of two transport devices, one on either side of the gap. With two transport units working simultaneously from both sides, the duration of activation was reduced by half. The devices remained adequately stable throughout the duration of the experiment, except for one instance, where the transport disc showed some tipping because of a faulty wing on the transport unit. The problem was corrected after replacement of the faulty wing.

An advantage of this design was the ability to compare a dentate and an edentulous transport disc in the same animal – an opportunity not afforded with more traditional transport

devices. There were two reasons to do this. One was that the toothed transport disc might show less dehiscence of the soft tissues than the more traditional edentulous discs. The other was that the presence of a tooth with intact periodontal ligament would provide versatility during oral maxillofacial rehabilitation of these highly compromised patients. Interestingly, only little dehiscence was noted for transport discs, mostly on the superior plate, while the advancing edge, lower half of the buccal surfaces and the entire lingual surfaces remained mostly intact. This was a satisfactory finding, given the massive scale of the procedure, inability to control animal behavior interfering with the wound, and difficulty of keeping perfect oral hygiene. The quality and quantity of bone regenerate was also similar whether the transport segment was dentate or edentulous.

A major limitation of bone transport distraction is still the lack of bone union at the docking site. All of the non-unions observed in this study were the result of soft tissue/gingiva--covered calluses abutting one another in the midline. However, this can be considered to be a relatively minor issue in these highly compromised patients. Once a jawline approximating the original mandible is re-established via the distraction process, the non-union can be repaired with a short surgical procedure to remove the intervening soft tissues and filling the remaining defect using cancellous bone graft, bone substitute, osteoinductive material, or a combination thereof. In any case, the lack of union between two adjacent bone segments should not overshadow the significant advantage of filling a huge defect with new viable bone that is identical to native bone without harvesting a large bone graft. This would represent a significant saving in time and morbidity during an already lengthy tumor excision surgery. By fine-tuning the technique of bone transport distraction and taking advantages of recent advances in the field of tissue engineering of bone, reconstruction of these challenging defects provides the oral maxillofacial surgeon with good alternate options in addition to current methods.

CONCLUSIONS

This study proved the feasibility of reconstructing a U-shaped curvilinear defect using bone transport distraction along a reconstruction plate using two different transport segments. The technique provides a viable alternative to vascularized grafts for the reconstruction of the critical anterior segment of the mandible after tumor excision. The use of dentate transport segment is also feasible and the resulting regenerate is comparable to that produced by transporting an edentulous segment.

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Figure 1.

Curvilinear version of the bone transport reconstruction plate (BTRP-02™) with two transport units for bilateral bone transport distraction. A, Drawing showing the BTRP-02™ in position on the mandible with two transport units attached to a dentate (arrow) and edentulous (arrowhead) transport disc, with newly formed regenerate in pink. B, BTRP-02™ showing the holes for attaching the device to the mandibular stumps (arrows) and the leaf-shaped plates on the transport units (asterisks) for attaching the units to the bone transport discs. C, Activation device (asterisk) shown in place on the advancing screw (arrow). One 360° turn of the screw advances the unit 1 mm.

Figure 2.

A, Intraoral photograph of distraction segments matching occlusal radiograph (C). Well vascularized mucosal covering of regenerate and transport discs is seen, along with prominent callus formation extending from the leading edge of the transport discs. Note remodeling of the floor of the mouth bringing the bottom lip back into the correct anatomic conformation with the new mandibular bone. B–D, Occlusal radiographs show bone quality of the regenerate on both sides with the advancement of the transport segments (asterisks) during bone transport distraction. B, One week after beginning distraction. C, Two weeks after beginning distraction. D, Three weeks after beginning distraction. E, Photo after six weeks consolidation. Radiographs showing improved quality of the regenerate bone at the end of the consolidation period. Note the remodeling of the transport disc bone to be indistinguishable from the regenerate bone.

Figure 3.

Cone-beam CT images showing sagittal views of the left and right mandible bodies (A, B), an anterior view of the midline (C) and an inferior view of the intact mandible (D). A, B, Representative images showing the comparable dimensions of the regenerate bone to the native bone behind the regenerate. C, D, The midline region showed an open gap, indicating that it was most likely held together at the symphysis by soft tissue.

Figure 4.

Low resolution Micro-CT scan showing the docking site for the transport discs. Anterior/symphysis regions for animals 1 to 5 (A–E, respectively) are shown. Note tooth roots in the right side transport segments of A, B, (arrows) and intact teeth in C, D, E (asterisks).

Figure 5.

High resolution Micro-CT scans of the regenerate bone of the left side (tooth extracted) and right side (tooth intact) of all five mandibles showing the distal, middle, and proximal regions. Note the presence of the alveolar canal in the distal segments, which appear to be reforming in the middle and proximal segments. Note the less organized appearance of the regenerate in the middle region of the right side segments.

Figure 6.

Micro-CT comparison between the proximal, middle, and distal regions of the right and left-side regenerate. Top row: Outline of the volume of interest used in micro CT analysis. Bar graphs show the Mean $\pm$ 2 SE values for proportional bone volume (BV/TV), connectivity density (Conn.D), structural model index (SMI), trabecular number (TB.N), trabecular thickness (Tb.Th), trabecular separation (Tb.Sp), apparent density, and material density.

Table 1

The number of days for distraction and consolidation in each animal.

	TOTAL NUMBER OF DAYS DISTRACTION	TOTAL NUMBER OF DAYS CONSOLIDATION
DOG 1	34 days	41 days
DOG 2	33 days	41 days
DOG 3	49 days	40 days
DOG 4	39 days	44 days
DOG 5	38 days	44 days

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